MHD velocity distribution and pressure drop in manifolds of a WCLL TBM

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Introduction

- In liquid metal blankets, lead lithium PbLi is foreseen as breeder, neutron multiplier, heat transfer medium.
- Flowing PbLi interacts with the plasma-confining magnetic field. Electric currents are induced that cause electromagnetic forces, high pressure drop and a distribution of electric potential inside fluid and electrically conducting walls.
- The design of manifolds which distribute PbLi into the WCLL TBM breeder zones is shown in Fig.1a. They consist of two poloidal ducts, electrically connected across a common wall.

Parameters characterizing the MHD flow

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
<th>Description</th>
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<tbody>
<tr>
<td>Hartmann number</td>
<td>( H_a = \frac{L B_m \sigma}{\nu} )</td>
<td>Non-dimensional measure for magnetic field strength ( B_0 )</td>
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<tr>
<td>Reynolds number</td>
<td>( R_e = \frac{u L}{\nu} )</td>
<td>Non-dimensional measure for mean velocity ( u_0 ) in breeding zone</td>
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<tr>
<td>Typical length</td>
<td>( L = \left( l_1 + t_{ss} + l_2 \right) / 4 = 0.048375 \text{ m} )</td>
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Numerical results

- Increased velocity in side layers, along walls parallel to the magnetic field \( B \), reduced velocity in the duct cores
- Significant 3D MHD effects near expansions and contractions, since the flow expands/contracts in \( B \) direction
- Strong influence of electromagnetic coupling of flows in adjacent fluid domains. As an example consider the flow in BZ1 in Fig.2a:
  - due to e.m. coupling flow in duct 2 pulls the one in the core of duct 1 in same direction
  - the resulting buildup of pressure drives reversed jets in duct 1

Fig.2 Flow at \( H_a = 4000, \ u_0 = 0.1 \text{ mm/s} \), (a) at the bottom of the module in BZ1, (b) in the middle in BZ5, (c) at the top in BZ8 (see Fig.1a). Above, 3D views of velocity distribution at three poloidal locations. Below, profiles of vertical velocity along the radial \( r \) coordinate, in the middle of the ducts.

Pressure distribution

- First estimation of pressure drop in manifolds of WCLL TBM gives acceptable values (Fig.3)
  - Other contributions should be considered, such as \( \Delta p \) in long PbLi supplying pipes
- Numerical results confirm scaling for MHD pressure drop under strong \( B \), \( \Delta p \sim \sigma B^2 u_0 \)
- Mean velocity along feeding/drainage manifold decreases/increases in poloidal direction
- Pressure drop along feeding/drainage manifold decreases/increases in \( pol \) direction

Pressure head between entrance and exit of breeder zones is not the same (see red arrows in Fig.3)

Flow imbalance is due to current manifold geometry in TBM design: cross-section of coupled ducts remains on average constant along poloidal fluid path, while flow rate changes by passing from BZ1 to BZ8.

EUROfusion

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